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A COMPREHENSIVE MULTIDISCIPLINARY PROGRAM FOR SPACE-TIME ADAPTIVE PROCESSING (STAP)

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The purpose of this effort was to perform focused research in the theory and strategies for space-time adaptive processing (STAP) in radar systems. The objective was to detect low flying targets in a severe clutter and jamming environment in real time. This was accomplished for Air Borne Radars by implementing two-dimensional adaptive filtering techniques in space (angle domain) and in time (Doppler domain) on High Performance Parallel computers. The initial simulations were carried out on the Maui HPCC.

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Background:

The need to detect low-flying vehicles in a severe clutter and jamming environment has led to development of space-time adaptive processing (STAP) techniques for airborne radars. It is well known that surface clutter returns are much more troublesome than those encountered by ground-based radars. Because of platform motion, the Doppler spread of the clutter returns is significantly wider and the clutter characteristics are highly variable due to the changing nature of the ground terrain being illuminated. Also, clutter power levels are much larger due to steeper aspect angles. When detection of long range and/or low observable targets is desired, higher transmit power levels are required and clutter problems are further aggravated.

Because of the doubly-spread nature of the clutter in space and Doppler frequency, clutter rejection in an airborne radar is often treated as a two-dimensional adaptive filtering problem in which the signal-to-clutter-plus- noise ratio (SCNR) is maximized. However, maximization of this ratio is equivalent to maximizing the probability of detection under a fixed probability of false alarm constraint only when the clutter and noise can be modeled as gaussian random processes. The vast majority of STAP algorithms appearing in the literature are based upon the gaussian assumption. The optimal gaussian receiver is a matched filter, or correlator, which maximizes SCNR by using space-time processing to filter out objectionable interference to the extent possible.

The proposal takes a two pronged approach to the STAP problem. The first method is to assume that the clutter is nongaussian and develop the methodology that is required to perform optimum processing. Next, introduce the newly developed results utilizing nongaussian statistics into the present methodology and observe how much better or worse the existing methods perform under the "nongaussian" approximation.

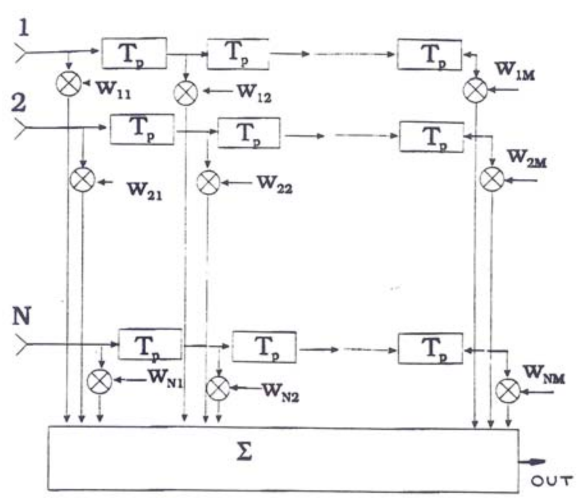

Figure 1. Space Time Model

The second approach is to set the adaptive space-time processing as a deterministic least squares problem. Consider N element antenna array as shown in Figure 1. Each antenna element has a tap-delay line with M taps. The taps in the delay line correspond to the pulse repetition frequency of the radar. So at a single snapshot one has access to the NM samples. The objective is now to weigh the NM signal samples by the weights $w_n(m)$ so that when they are summed the weak signal is recovered in the presence of coherent jammers, strong clutter and large reflections from nearfield scatterers.

In conventional STAP, one takes a few snapshots of the NM samples and estimates the covariance matrix of the data assuming stationarity and proceeds with the analysis. Inherent in the assumption of stationarity is that one replaces the expected value over ensemble averages by time averages. In airborne systems, the assumption of stationarity is in question. Hence we deal with each snapshot separately - or equivalently deal with each realization of the ensemble separately, rather than dealing with the entire ensemble at a time and thereby tacitly assume a probability density function. By dealing with each realization in the ensemble of snapshots separately, our approach appears to be a deterministic one, as in a probability space each realization in the ensemble is deterministic.

Research Objectives:

The purpose of this effort was to perform focused research in the theory and strategies for space-time adaptive processing (STAP) in radar systems. The objective was to detect low flying targets in a severe clutter and jamming environment in real time. This was accomplished for Air Borne Radars by implementing two-dimensional adaptive filtering techniques in space (angle domain) and in time (doppler domain) on High Performance Parallel computers. The initial simulations were carried out on the Maui HPCC.

Methodology:

The objective of this research effort was to develop a direct least squares approach to Space-Time Adaptive Processing (STAP) for airborne wide area surveillance radar. The novelty of this approach lies in the fact that the performance of our least squares (LS) processor depends only on the measured data in the test (or primary) cell and requires no assumptions about homogeneous reference (or secondary) data from which under lying statistics must be estimated. This is one important reason that the LS solution the adaptive radar clutter and jammer interference rejection problem naturally lends itself to a parallel processing implementation, since each range cell may be analyzed on a different node. Often, accurate statistical parameter estimation is not even possible due to violation of the homogeneity assumption in the real world and so the sample covariance matrix based STAP will fail to meet performance expectations. To this end, the direct least squares solution is being developed for STAP and is presently being implemented. Currently analysis is under way to check the performance of this new technique on experimental data. Additionally merging of the signal processing approach with an electromagnetic based solution to the mutual coupling problem in

multichannel phased array radars provides for improved performance over conventional Sample Matrix Inversion (SMI) based STAP processors, when operating in nonhomogeneous environment. The SMI approach to STAP has been implemented on an IBM SP2 for performance comparison. A study of various computer architectures has been completed. Currently efforts are under way to implement the direct LS approach to STAP on the Maui High Performance Computing Center utilizing the IBM SP2 for further performance comparison with real data.

Accomplishments:

A direct data domain approach was developed for adaptively processing a received signal coming from a given direction in the presence of strong jammers and clutter. This method is ideally suited in highly nonstationary environments particularly in the presence of blinking jammers and for problems where the clutter characteristics change quite rapidly. Also, a methodology was presented which prevents signal cancellation and the direction of arrival is not known precisely. The application of this methodology will be quite useful in mobile communications where the undesired signal characteristics change quite rapidly while providing acceptable reception of the desired signal. This will result in improving the characteristics of receivers used in wireless communications which of course includes all air-borne radars.

Additionally, a STAP algorithm was mapped onto the IBM SP2 architecture. The STAP algorithm that was considered is the Extended Factor Adaptive (EFA) STAP method. The basic guideline followed in mapping the EFA STAP algorithm onto the massively parallel system, the IBM SP2, was to minimize as much as possible communications between processors. The rationale being that this process would enable us to map the direct LS algorithm onto the same system and would enable us to compare performance between the various algorithms on real data on the same system.

A survey of various computer architectures was made to see which system would be more suitable for the solution of very large complex matrix equations that arise in the solution of electromagnetic field problems that arise in phased array radars. As one of the objectives of the effort was to eliminate mutual coupling between antenna elements so that signal processing techniques can be applied with greater speed and accuracy, it was necessary to couple the solution between the electromagnetic field problem and the signal processing problem. The objective of this effort was to see which computer architecture would be most suitable to solve the adaptive problem on airborne radars in real time.

The results obtained from this research were used to educate engineers at Rome laboratory on “Multichannel Adaptive Filtering with Application to Space-Time Processing”. The software was also included in the Rome Laboratory RLSTAP/ADT (Algorithm Development Tool). Additionally, this research resulted in 7 journal papers which are listed below.

1. Sarkar, T. K., Park, S., Koh, J. and Schneible, R. A., "A Deterministic Least Squares Approach to Adaptive Antennas", Digital Signal Processing, A Review Journal, Vol. 6, No. 3, 1996, pp. 185-194.

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